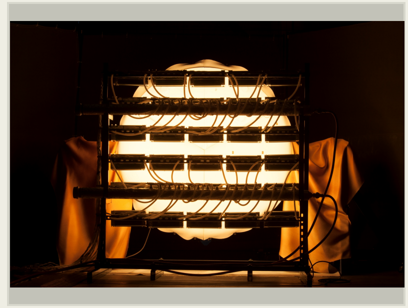
Monitoring of Thermal Protection Systems using Robust Self-Organizing Optical Fiber Sensing Networks

Completed Technology Project (2011 - 2015)

Project Introduction

Effective thermal protection systems are crucial for spacecraft or future hypersonic transports re-entering the atmosphere. Micro-meteoroids and orbital debris (MMODs) are an increasingly dangerous problem for near-Earth operations. This system uses a network of optical fiber sensors to map heat shield strains and temperatures using decentralized "agent based" algorithms in a sensor network.

Virtually every program across the agency needs the ability to detect and assess the impact of MMOD. We are developing and demonstrating robust, dynamically-reconfigurable optical fiber sensor networks for on-orbit damage detection. Objectives The project has the following objectives: a) Development, evaluation and demonstration of a dynamically reconfigurable optical fiber sensing network that is interrogated using the optical frequency domain reflectometry (OFDR) technique. Such a system will substantially reduce the susceptibility of optical fiber sensing systems to failure in the event of fiber breakage. b) Development and demonstration of a distributed, self-organized approach to configuration control of an optical fiber sensing network that is interrogated using the optical frequency domain reflectometry (OFDR) technique. c) Demonstrate fiber optic distributed strain and temperature sensing on a small-scale heat shield carrier structure. d) Development and demonstration of a method for determining optimal sensor placements with the aim of maintaining adequate accuracy of impact and damage location. e) Development and demonstration of acoustic detection and thermal evaluation of impact damage to a thermal protection system (TPS) attached to the carrier structure of goal c) above. Approach This work will be carried out jointly by Armstrong Flight Research Center and CSIRO Materials Science & Engineering, Sydney, Australia. It will leverage off developments from earlier NASA/CSIRO work on structural health monitoring, in particular on the development of a distributed multi-agent system demonstrator for impact detection and damage characterization, which was co-funded by CSIRO. Principle of combined acoustic emission/thermal monitoring of TPS The general aim of this work is to develop and demonstrate a prototype structural health monitoring system for thermal protection systems (TPS) that incorporates piezoelectric acoustic emission (AE) sensors to detect the occurrence and location of damaging impacts, and an optical fiber Bragg grating (FBG) sensor network to evaluate the effect of detected damage on the thermal conductivity of the TPS material. Following detection of an impact, the TPS would be exposed to a heat source, possibly the sun, and the temperature distribution on the inner surface in the vicinity of the impact measured by the FBG network. A similar procedure could also be carried out as a screening test immediately prior to re-entry. The implications of any detected anomalies in the measured temperature distribution will be evaluated for their significance in relation to the performance of the TPS during re-entry. Structure of optical fiber network An important aspect of this proposal is the development of a robust, electronically-reconfigurable FBG network that employs the optical frequency



TPS HMS Demo Thermal Test

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domain reflectometry (OFDR) technique to measure temperature-induced strains in the Bragg gratings. The network will have a high degree of redundancy to ensure its continued effectiveness in the event of damage to one or more fiber segments. Light will be routed around damaged fiber segments, so that the network can continue to operate even when some regions of it are damaged. Network routing/configuration could be: i) controlled from a central processor, using wired or wireless communications; or ii) determined using a distributed, self-organized approach to control of the sensor network. This approach has been outlined in a recent Contractor Report (Scott & Price, NASA/CR-2007-215092). Both these approaches will be demonstrated, the former as a bench-top demonstration to establish the feasibility of the principle of OFDR in a switched FBG network (by end FY11), and the latter as a fundamental component of the TPS health monitoring application demonstrator. Proposed demonstrator architecture and structure The project will build a demonstration structure that loosely simulates a segmented, circular ablative thermal protection system (a developmental prototype segmented ablative TPS has recently been developed for the Orion CEV program by Boeing). The structure will consist of three layers: a metallic carrier, a bond layer and the TPS layer, which will be fabricated from a material whose acoustic and thermal properties should be similar to those of a relevant heat shield material. A comprehensive program of measurement of the acoustic and thermal properties of the materials used in the demonstrator structure will be carried out in order to underpin the development of computational models of acoustic and thermal propagation within the structure. Acoustic and thermal modeling will be used to determine sensor densities and placements: piezoelectric AE sensors will be bonded to one surface of the carrier and the FBG network described above will be embedded in the bond layer, adjacent to the TPS material. A second FBG sensing network, with sensors separately configured to measure temperature and strain, will be mounted on the inside surface of the carrier structure to measure effects of high temperature and mechanical strain on the structure (objective c). Schematics of the demonstration structure will be provided in the presentation. The final outcome of the project will be incorporation of the monitoring system into a larger-scale TPS experimental structure at Armstrong (in FY15). Electronic system architecture The proposed electronic control, data acquisition and processing system is based on the architecture of a distributed multi-agent system. Such a system has already been developed and demonstrated for detection and diagnosis of impact damage, as part of a collaboration between NASA and CSIRO. (NASA Contractor ReportNASA/CR-2010-216186). Individual autonomous sensing agents each control a local group of AE sensors and routing switches for the FBG network. Each agent can communicate with its nearest neighbors. Local algorithms that control the communication of information around the network of agents will allow the system to collectively determine the most appropriate path for light propagation through the FBG network, and will enable thermal information obtained by the sensors to be returned to the appropriate local agents. The benefits of a system such as this over a conventional centrally-controlled

Organizational Responsibility

Responsible Mission Directorate:

Office of Safety and Mission Assurance (OSMA)

Lead Center / Facility:

Armstrong Flight Research Center (AFRC)

Responsible Program:

Nondestructive Evaluation Program

Project Management

Program Director:

Terrence W Wilcutt

Program Managers:

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Jason P Moore
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Project Manager:

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Principal Investigators:

Larry D Hudson
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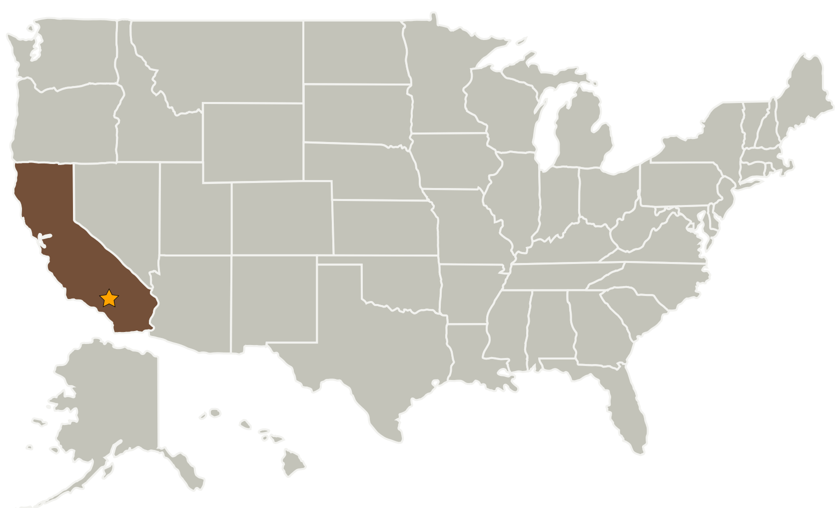
network include robustness (there is no single point of failure, and the network can continue to function in the presence of damage in some areas), scalability (the number of agents and sensors can be greatly increased without degrading system performance) and ability to respond effectively to dynamic environments.   Customers NASA, HEOMD, STMD   Products Electronically-reconfigurable optical fiber sensor network. Self-organizing distributed system for optimal routing of light in FBG network. Demonstration prototype for health monitoring of ablative TPS.

Anticipated Benefits

The benefits of a system such as this over a conventional centrally-controlled network include robustness (there is no single point of failure, and the network can continue to function in the presence of damage in some areas), scalability (the number of agents and sensors can be greatly increased without degrading system performance) and ability to respond effectively to dynamic environments.

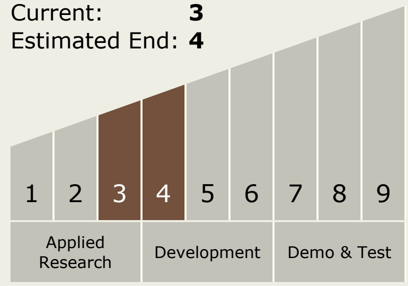
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Armstrong Flight Research Center(AFRC)	Lead Organization	NASA Center	Edwards, California

Technology Maturity (TRL)

Start: **3**
Current: **3**
Estimated End: **4**



Technology Areas

Primary:

- TX14 Thermal Management Systems
  - └ TX14.3 Thermal Protection Components and Systems
    - └ TX14.3.5 Thermal Protection System Instrumentation

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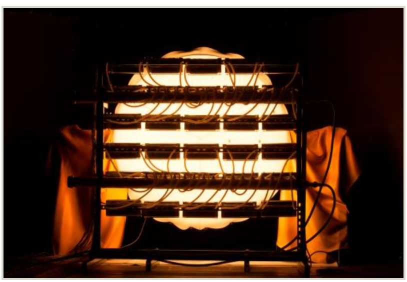
Co-Funding Partners	Type	Location
Commonwealth Scientific and Industrial Research Organization(CSIRO)	Industry	Canberra, Outside the United States, Australia

Primary U.S. Work Locations
California

Images



TPS HMS Demo
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